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(54) HIGH-FREQUENCY DIRECT CURRENT BULK CAPACITORS WITH INTERLEAVED BUSBAR PACKAGES

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H05K 7/14	(2006.01)
B60M 1/30	(2006.01)
B60L 15/00	(2006.01)
B60L 50/61	(2019.01)

(52) **U.S. Cl.**

CPC ***B60L 50/40*** (2019.02); ***B60L 15/007*** (2013.01); ***B60L 50/61*** (2019.02); ***B60M 1/30*** (2013.01); ***H02M 7/003*** (2013.01); ***H05K 7/1432*** (2013.01)

(58) **Field of Classification Search**

CPC H05K 7/1432; H05K 7/20845–20881; H02M 7/003

See application file for complete search history.

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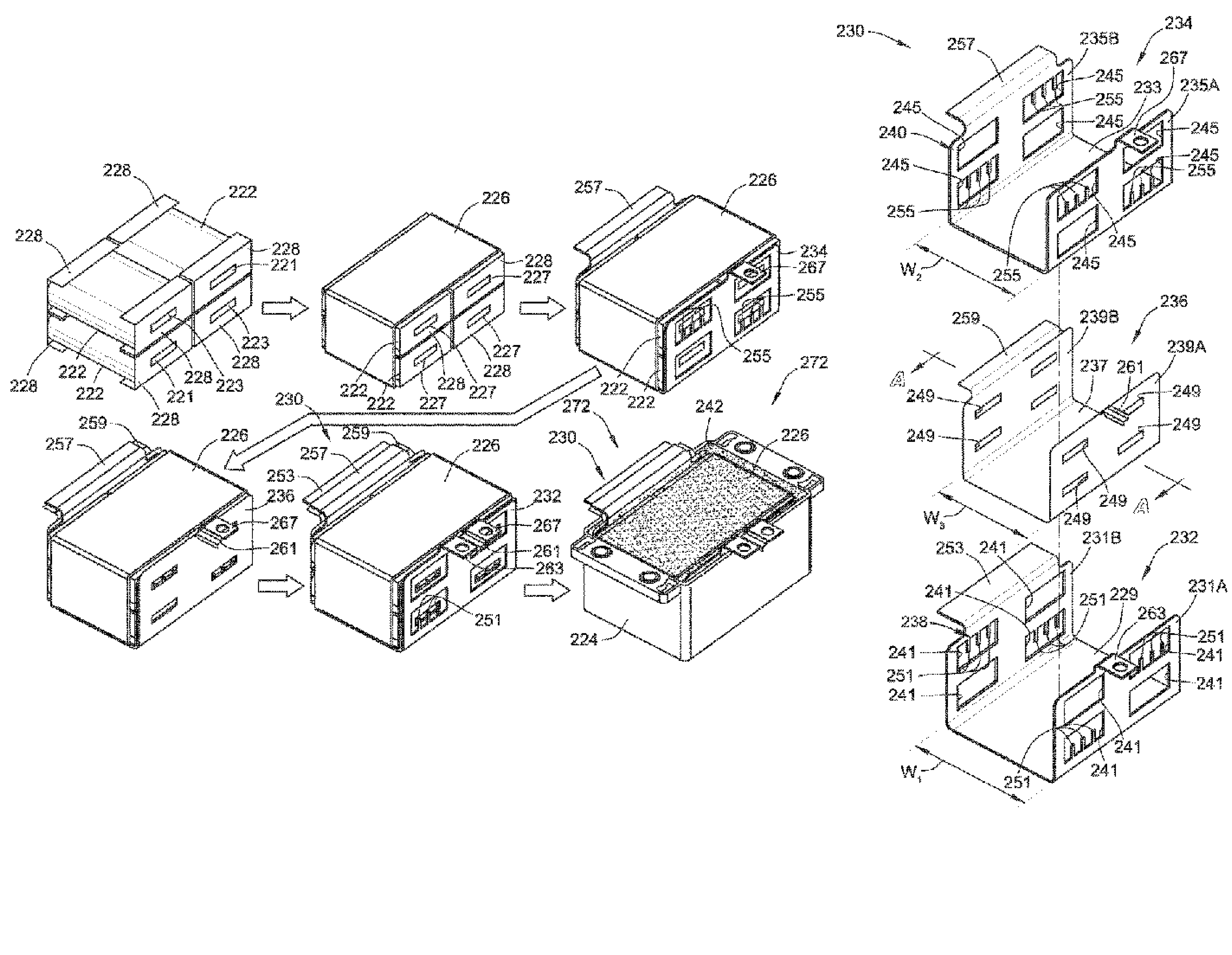
(57) **ABSTRACT**

Presented are electrical capacitors with interleaved busbar architectures, methods for making/operating such capacitors, and electric-drive vehicles equipped with such capacitors. A bulk capacitor includes multiple capacitor devices disposed within an outer housing and operable to modify electric current transmitted between a power source and an electrical load. An interleaved busbar package is interposed between the capacitor devices and outer housing. The interleaved busbar package includes a first busbar plate that electrically connects to first terminals of the capacitor devices and defines a busbar pocket. A second busbar plate is seated within the busbar pocket and electrically connects to second terminals of the capacitor devices. The second busbar plate includes a capacitor basin that seats therein the capacitor devices. An isolator sheet is interleaved between and electrically insulates the first and second busbar plates. The capacitor devices and interleaved busbar package may be partially submerged in an epoxy endfill composition.

20 Claims, 5 Drawing Sheets



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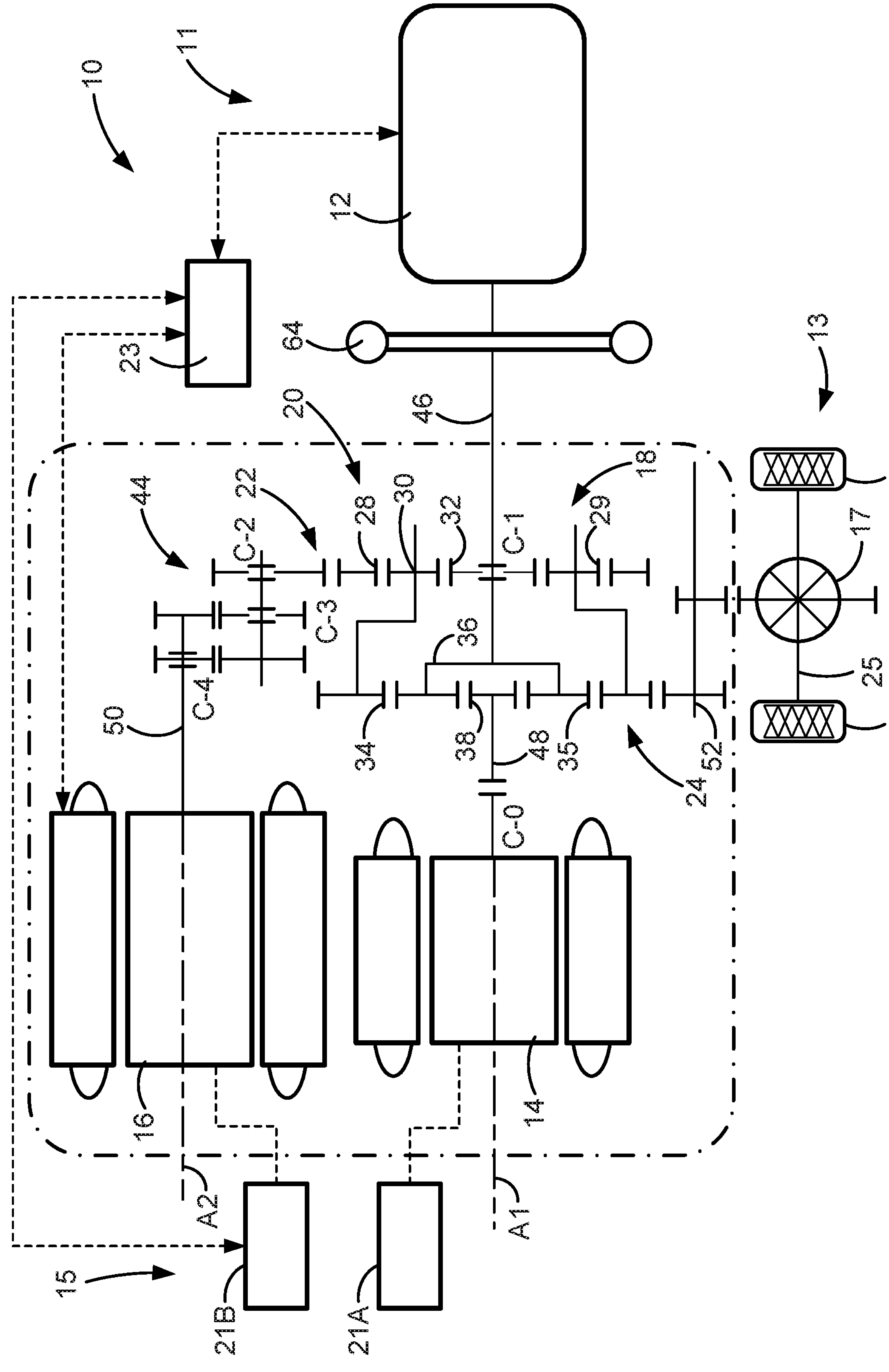
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FIG. 1

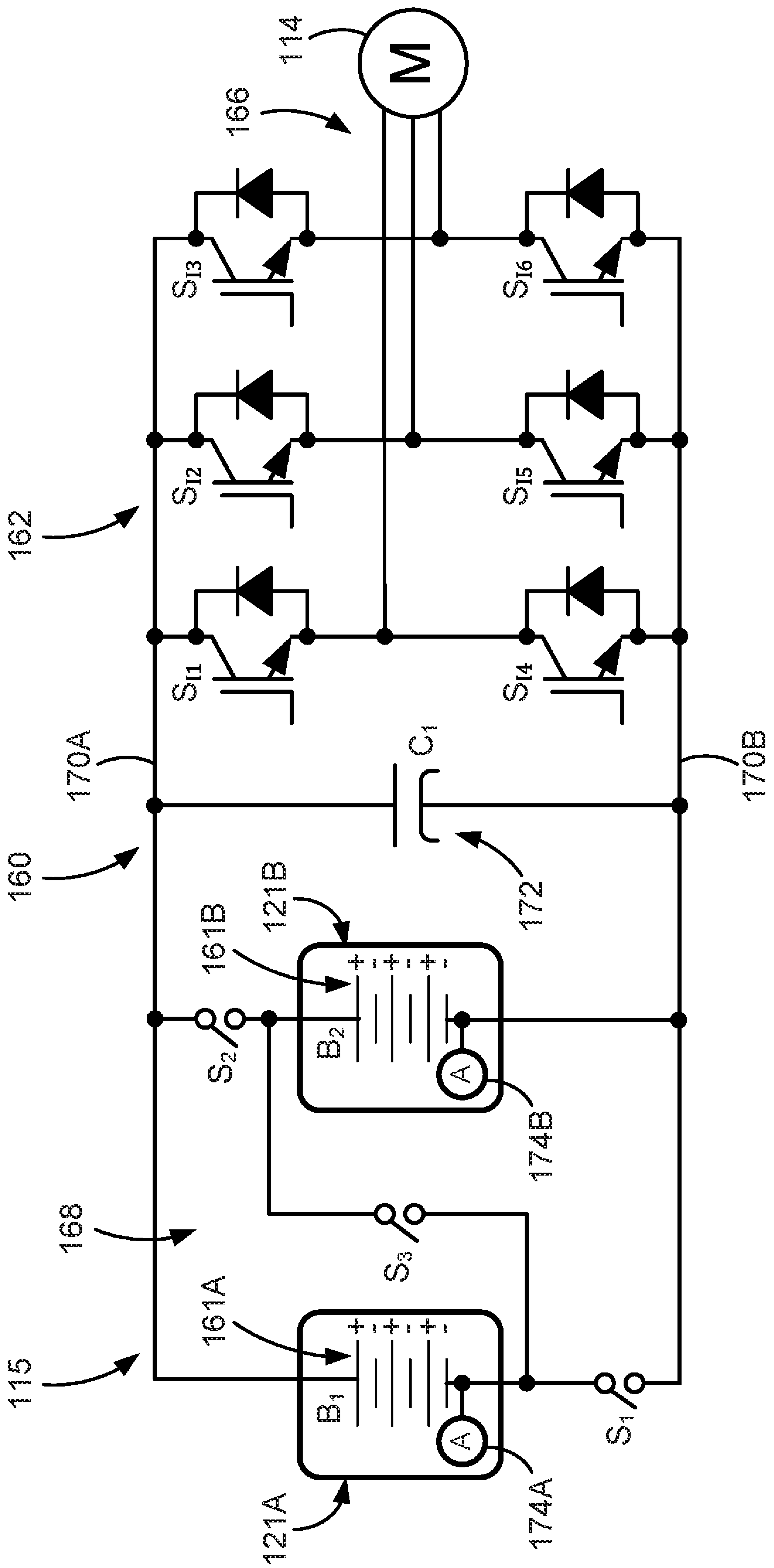
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FIG. 2

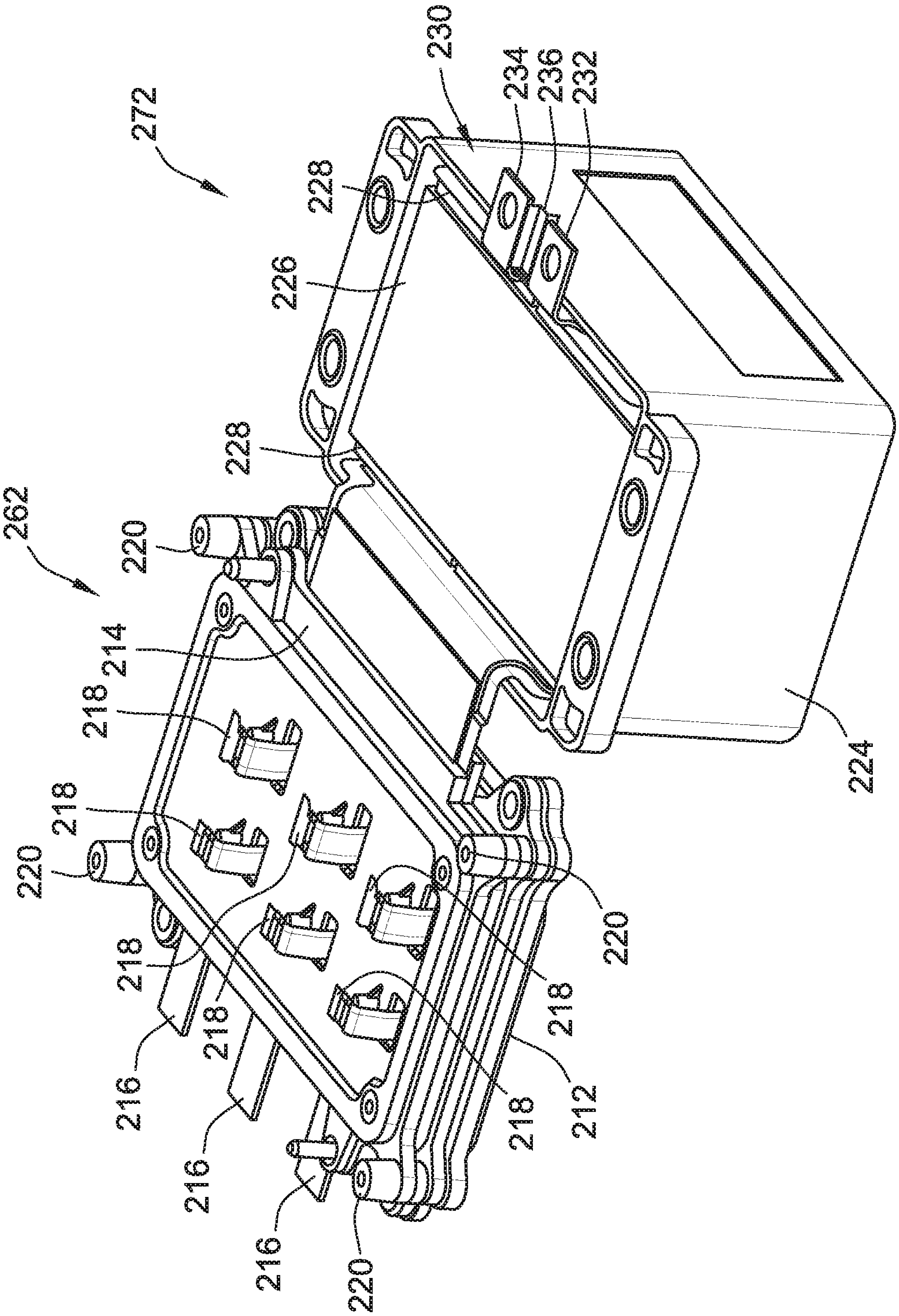
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FIG. 3

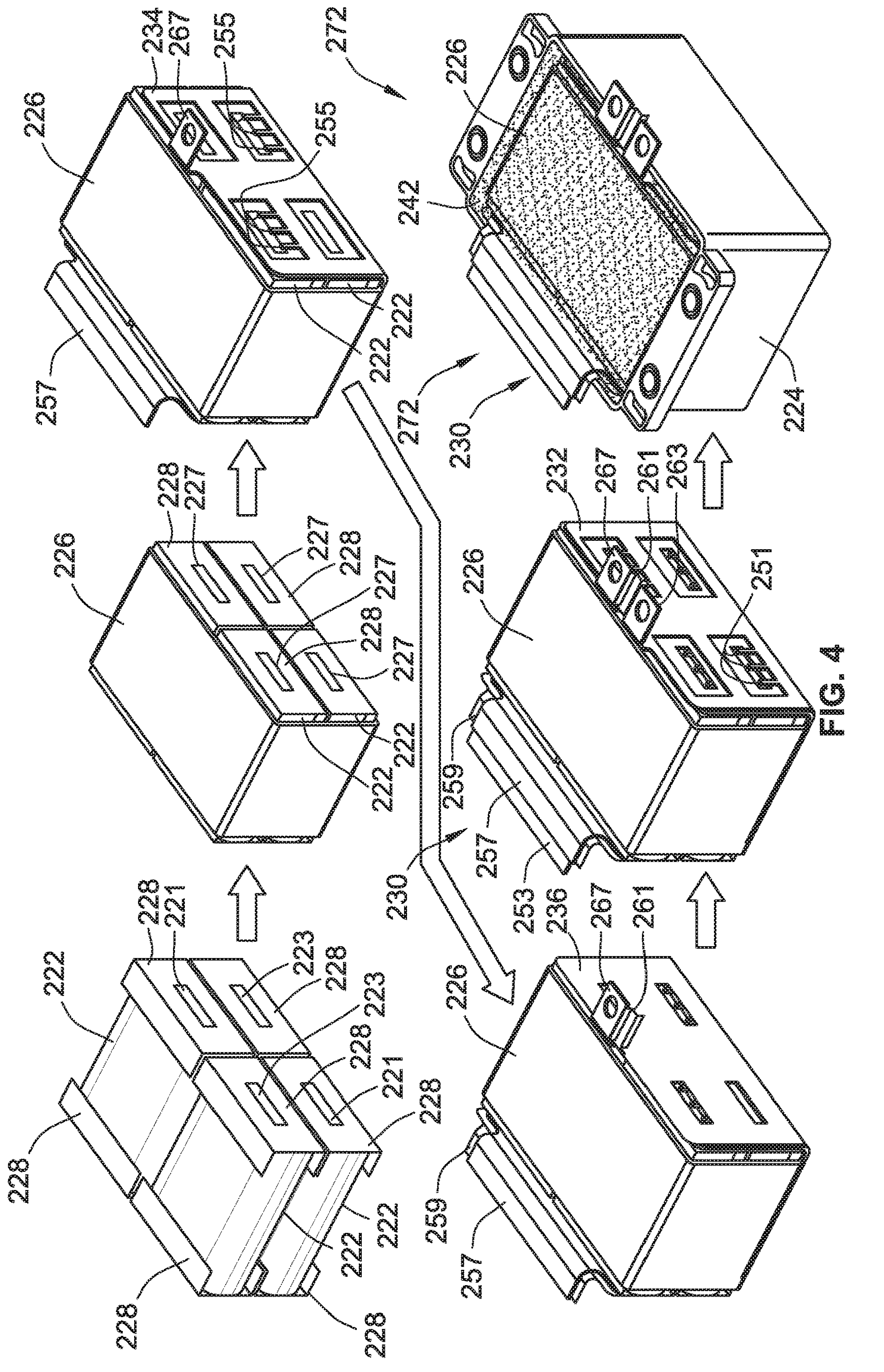
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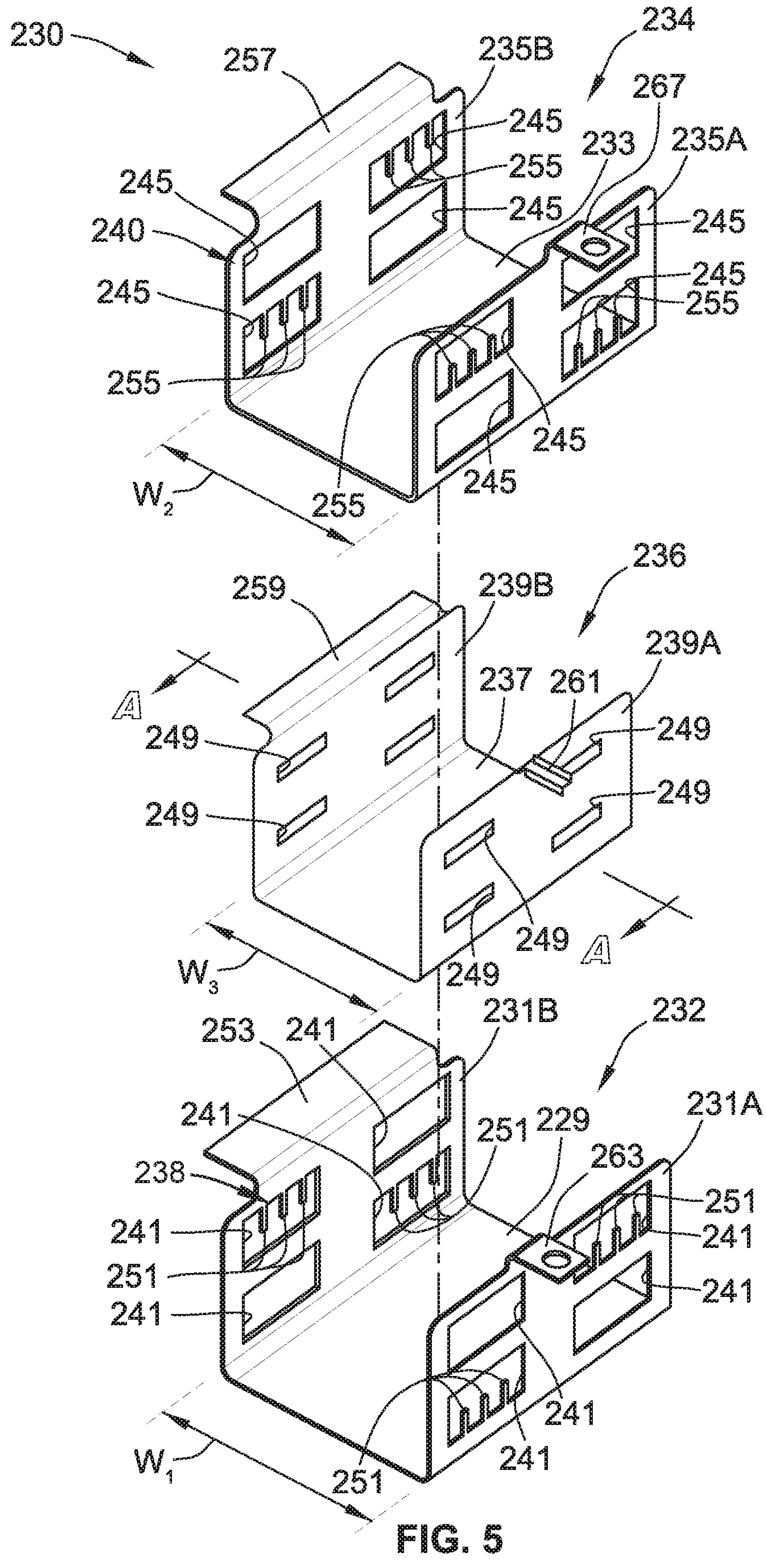
FIG. 4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W3
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241
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W1
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FIG. 5

HIGH-FREQUENCY DIRECT CURRENT BULK CAPACITORS WITH INTERLEAVED BUSBAR PACKAGES

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

This invention was made with government support under Contract No. DE-EE-0007285 awarded by the U.S. Department of Energy (DOE); the government has certain rights in the invention.

INTRODUCTION

The present disclosure relates generally to high-voltage electric power systems. More specifically, aspects of this disclosure relate to high-frequency, direct current (DC) bulk capacitors for hybrid and electric ("electric-drive") motor vehicles.

Current production motor vehicles, such as the modern-day automobile, are originally equipped with a powertrain that operates to propel the vehicle and power the vehicle's onboard electronics. In automotive applications, for example, the vehicle powertrain is generally typified by a prime mover that delivers driving power through an automatic or manually shifted power transmission to the vehicle's final drive system (e.g., differential, axle shafts, road wheels, etc.). Automobiles have historically been powered by a reciprocating-piston type internal combustion engine (ICE) assembly due to its ready availability and relatively inexpensive cost, light weight, and overall efficiency. Such engines include compression-ignited (CI) diesel engines, spark-ignited (SI) gasoline engines, and rotary engines, as some non-limiting examples. Hybrid and full electric vehicles, on the other hand, utilize alternative power sources to propel the vehicle and, thus, minimize or eliminate reliance on a fossil-fuel based engine for tractive power.

A full electric vehicle (FEV)—colloquially referred to as an "electric car"—is a type of electric-drive vehicle configuration that altogether removes the internal combustion engine and attendant peripheral components from the powertrain system, relying solely on electric traction motors for propulsion and for supporting accessory loads. The engine, fuel supply system, and exhaust system of an ICE-based vehicle are replaced with an electric motor, a traction battery back, and battery cooling and charging electronics in an FEV. Hybrid vehicle powertrains, in contrast, employ multiple sources of tractive power to propel the vehicle, most commonly operating an internal combustion engine assembly in conjunction with a battery-powered or fuel-cell-powered electric traction motor. Since hybrid vehicles are able to derive their power from sources other than the engine, hybrid electric vehicle (HEV) engines may be turned off, in whole or in part, while the vehicle is propelled by the electric motor(s).

Most commercially available hybrid and electric vehicles employ a rechargeable traction battery pack (also referred to as "electric-vehicle battery" or "EVB") to store and supply the requisite power for operating the powertrain's motor/generator unit(s). A traction battery pack, which is significantly larger, more powerful, and higher in capacity than a 12-volt starting, lighting, and ignition (SLI) battery, groups stacks of battery cells into individual battery modules that are mounted onto the vehicle chassis, e.g., via a battery housing or support tray. Some vehicle battery systems employ multiple independently-operable, high-voltage battery packs to provide higher voltage delivery and greater system capacity through increased amp-hours. A dedicated Battery Pack Control Module (BPCM) regulates the opening and closing of battery pack contactors to govern which pack or packs will power the vehicle's traction motor(s) at a given time. While the vehicle is in operation, the battery system may switch from one pack to another in a manner that protects the battery packs and contactors while ensuring a constant feed of voltage so as to not interfere with powertrain functionality.

High-voltage electric power systems govern the transfer of electricity between the traction motor(s) and battery pack(s) of electric-drive vehicles. The electric circuit may employ a front-end DC-to-DC electric power converter that is electrically connected to the vehicle's traction battery pack(s) in order to increase the supply of voltage to a high-voltage main DC bus and an electronic power inverter. A high-frequency bulk capacitor may be arranged across the positive and negative terminals of the main DC bus to provide electrical stability and store supplemental electric energy. Bulk capacitor size—in terms of total capacitance—may be selected based upon expected DC bus voltage range, peak current and ripple voltage when operating the inverter employing, for example, a six-step mode of operation. Operation and control of multi-phase electric motor/generator units, such as permanent magnet synchronous traction motors, may be accomplished by employing the inverter to transform DC electric power to alternating current (AC) power using pulse-width modulated control signals output from a resident controller.

SUMMARY

Disclosed herein are electrical capacitors with interleaved busbar architectures, methods for making and methods for operating such capacitors, high-voltage electric power circuits using such capacitors, and electric-drive vehicles equipped with such capacitors. By way of example, and not limitation, there are presented high-frequency DC bulk capacitors with interleaved busbar packages for reduced parasitic inductance, improved current sharing symmetry, and increased switching frequency capabilities. The interleaved busbar package includes two electrically conductive busbar plates fabricated with complementary U-shaped geometries that enable one busbar to nest within the other busbar. A similarly U-shaped electrical insulator, which may be in the nature of an aramid paper or a polyester or epoxy-glass sheet, is sandwiched between the superposed busbar conductors. Once assembled, the interleaved busbar package forms a basin that seats therein a stack of capacitor bobbins, which may be arrayed in juxtaposed columns of bobbin pairs. The array of capacitor bobbins may be wrapped in an electrically insulating jacket, with discrete insulation endcaps placed on distal ends of each bobbin. After seating the insulated bobbins within the busbar package, the subassembly may be mounted inside a capacitor housing while concomitantly submerged within an epoxy endfill composition, e.g., in a "wrap & fill" configuration. Terminal tabs at distal ends of the busbar conductors may be electrically connected, e.g., via laser welding, to a power inverter module (PIM).

Attendant benefits for at least some of the disclosed DC bulk capacitor architectures include minimized total power stage inductance (e.g., a five-time reduction over comparable packaging solutions). In addition to a measurable reduction in parasitic inductance, disclosed capacitor designs enable utilization of wide bandgap devices at increased slew rate speeds and thereby reduce power losses of traction inverters. Other attendant benefits may include improved bulk capacitor packaging that reduces the overall size, weight, and cost of a traction inverter. Disclosed systems, methods, and devices may also enable equal current sharing among the capacitor bobbins to provision the symmetric distribution of current stresses. Proposed capacitor packages may also enable operation of the power inverter module at high switching frequencies and slew rates such that the module may be used for boost converter applications. Laser welding of the DC bulk capacitor to a power inverter module provisions a low resistance and low inductance connection between the two components. An interleaved busbar package, as disclosed herein, may be modular and, thus, can be scaled to accommodate different numbers of capacitor bobbins. For automotive applications, it is envisioned that use of disclosed DC bulk capacitor designs will help to effectively increase the "miles per gallon" rating of electric-drive vehicles.

Aspects of this disclosure are directed to high-frequency DC bulk capacitors with interleaved busbar packages, e.g., for filtering current flow across a high-voltage main DC bus. In an example, a bulk capacitor is presented that includes an outer housing within which is stored multiple capacitor devices, such as side-by-side stacks of wound film capacitors. These capacitor devices cooperatively modify electric currents transmitted back-and-forth between a power source, such as a traction battery pack, and an electrical load, such as a traction motor. An interleaved busbar package is interposed between and separates the capacitor devices and outer housing. The interleaved busbar package includes a first (negative) busbar plate that electrically connects to first (negative) terminals of the capacitor devices. A second (positive) busbar plate, which is seated within a busbar pocket formed into the first busbar plate, electrically connects to second (positive) terminals of the capacitor devices. The second busbar plate is formed with a capacitor basin that seats therein and partially surrounds the capacitor devices. An isolator sheet is interleaved between the two busbar plates to electrically insulate the first busbar plate from the second busbar plate.

Additional aspects of this disclosure are directed to electric-drive vehicles and electrified vehicle powertrains equipped with high-frequency DC bulk capacitors with interleaved busbar packages. As used herein, the term "motor vehicle" may include any relevant vehicle platform, such as passenger vehicles (ICE, REV, FEV, fuel cell, fully and partially autonomous, etc.), commercial vehicles, industrial vehicles, tracked vehicles, off-road and all-terrain vehicles (ATV), motorcycles, farm equipment, watercraft, aircraft, etc. In an example, an electric-drive vehicle includes a vehicle body with multiple road wheels and other standard original equipment. Mounted on the vehicle body is one or more electric traction motors that selectively drive one or more of the road wheels to thereby propel the vehicle. Also mounted on the vehicle body is one or more rechargeable traction battery packs that selectively store and transmit electric current to power the traction motor(s). The battery pack(s) and motor(s) may be interconnected via a high-voltage electric circuit.

Continuing with the above example, the vehicle's energy storage system also includes a bulk capacitor with an electrically insulating outer housing that is mounted onto the vehicle body. An array of stacked capacitor devices is packaged within the outer housing and operable to filter or otherwise modify electric currents transmitted between the traction battery pack(s) and traction motor(s). An interleaved busbar package is placed between and separates the capacitor devices and outer housing. The interleaved busbar package includes a first (negative) busbar plate with a busbar pocket that seats therein a second (positive) busbar plate. The first busbar plate is electrically connected to first (negative) terminals of the capacitor devices, whereas the second busbar plate is electrically connected to second (positive) terminals of the capacitor devices. The second busbar plate has a capacitor basin that seats therein and partially surrounds the arrayed capacitor devices. An isolator sheet is interleaved between the two busbar plates to electrically insulate the first busbar plate from the second busbar plate.

Other aspects of the disclosure are directed to methods for making and methods for using any of the disclosed capacitor assemblies, electrical systems, powertrains, and vehicles. In an example, a method is presented for assembling a bulk capacitor. This representative method includes, in any order and in any combination with any of the above and below disclosed options and features: placing a plurality of capacitor devices within an outer housing, the capacitor devices being operable to modify an electric current transmitted between a power source and an electrical load; and positioning an interleaved busbar package between the outer housing and capacitor devices, the positioning of the busbar package including: electrically connecting a first busbar plate to first terminals of the capacitor devices, the first busbar plate defining a busbar pocket; electrically connecting a second busbar plate to second terminals of the capacitor devices, the second busbar plate being seated within the busbar pocket and defining a capacitor basin seating therein the capacitor devices; and interleaving an isolator sheet between the busbar plates to thereby electrically insulate the first busbar plate from the second busbar plate.

For any of the disclosed systems, methods, and devices, each busbar plate may have a U-shaped cross-section with the second busbar plate's U-shaped cross-section being slightly narrower than the first busbar plate's U-shaped cross-section. With this configuration, the first and second busbar plates may nest substantially coterminous with each other such that sidewalls of the two busbar plates are mutually parallel, while bases of the two busbar plates are substantially parallel with one another. In the same vein, the isolator sheet may have a respective U-shaped cross-section that is narrower than the first busbar plate's U-shaped cross-section yet wider than the second busbar plate's U-shaped cross-section. With this configuration, the isolator sheet's base lays substantially flush against both bases of the first and second busbar plates, and the isolator sheet's sidewalls lay substantially flush against respective sidewalls of the two busbar plates.

For any of the disclosed systems, methods, and devices, each busbar plate may have a pair of sidewalls that adjoin and project substantially orthogonally from a base. As a further option, each busbar plate sidewall may be fabricated with multiple windows that extend through the sidewall. Each of these windows is aligned with a longitudinal end of a capacitor device. Electrical fingers may project into some, but not all, of the busbar plate windows; these fingers electrically connect to the terminals of the capacitor devices. In addition, each busbar plate may be fabricated with a connector pad that projects transversely from one sidewall and electrically connects to the electrical load. A connector tab may project from the other sidewall and electrically connect to the power source. As yet a further option, the isolator sheet may have a pair of sidewalls that adjoin and project substantially orthogonally from a base. An optional pad isolator projects from one of the isolator sheet's sidewalls and interleaves between the connector pads of the two busbar plates. A tab isolator may project from the other isolator sheet sidewall and interpose between the connector tabs of the busbar plates. A lining jacket may be wrapped around and electrically insulate an outer perimeter of the capacitor array.

The above summary is not intended to represent every embodiment or every aspect of the present disclosure. Rather, the foregoing summary merely provides an exemplification of some of the novel concepts and features set forth herein. The above features and advantages, and other features and attendant advantages of this disclosure, will be readily apparent from the following detailed description of illustrated examples and representative modes for carrying out the present disclosure when taken in connection with the accompanying drawings and the appended claims. Moreover, this disclosure expressly includes any and all combinations and subcombinations of the elements and features presented above and below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram illustrating a representative power-split hybrid powertrain architecture of an electric-drive motor vehicle with a DC bulk capacitor in accordance with aspects of the present disclosure.

FIG. **2** is a schematic diagram illustrating a representative electric-drive vehicle battery system with multiple traction battery packs and a high-voltage main DC bus with a DC bulk capacitor in accordance with aspects of the present disclosure.

FIG. **3** is a perspective-view illustration of a representative power inverter module laser welded to a representative high-frequency DC bulk capacitor with interleaved busbar package in accordance with aspects of the present disclosure.

FIG. **4** is a workflow diagram illustrating a representative manufacturing method for constructing the bulk capacitor of FIG. **3**.

FIG. **5** is an exploded, perspective-view illustration of the representative interleaved busbar package of FIG. **3**.

The present disclosure is amenable to various modifications and alternative forms, and some representative embodiments are shown by way of example in the drawings and will be described in detail herein. It should be understood, however, that the novel aspects of this disclosure are not limited to the particular forms illustrated in the above-enumerated drawings. Rather, the disclosure is to cover all modifications, equivalents, combinations, subcombinations, permutations, groupings, and alternatives falling within the scope of this disclosure as encompassed by the appended claims.

DETAILED DESCRIPTION

This disclosure is susceptible of embodiment in many different forms. Representative embodiments of the disclosure are shown in the drawings and will herein be described in detail with the understanding that these embodiments are provided as an exemplification of the disclosed principles, not limitations of the broad aspects of the disclosure. To that extent, elements and limitations that are described, for example, in the Abstract, Introduction, Summary, and Detailed Description sections, but not explicitly set forth in the claims, should not be incorporated into the claims, singly or collectively, by implication, inference or otherwise.

For purposes of the present detailed description, unless specifically disclaimed: the singular includes the plural and vice versa; the words "and" and "or" shall be both conjunctive and disjunctive; the words "any" and "all" shall both mean "any and all"; and the words "including," "containing," "comprising," "having," and the like, shall each mean "including without limitation." Moreover, words of approximation, such as "about," "almost," "substantially," "generally," "approximately," and the like, may each be used herein in the sense of "at, near, or nearly at," or "within 0-5% of," or "within acceptable manufacturing tolerances," or any logical combination thereof, for example. Lastly, directional adjectives and adverbs, such as fore, aft, inboard, outboard, starboard, port, vertical, horizontal, upward, downward, front, back, left, right, etc., may be with respect to a motor vehicle, such as a forward driving direction of a motor vehicle when the vehicle is operatively oriented on a normal driving surface.

Referring now to the drawings, wherein like reference numbers refer to like features throughout the several views, there is shown in FIG. **1** a schematic illustration of a representative automobile, which is designated generally at **10** and portrayed herein for purposes of discussion as a hybrid electric vehicle. In accord with a more specific, non-limiting example, the powertrain **11** is a dual-mode, power-split hybrid electric powertrain with a variable-displacement 6.0-liter V8 engine **12** and two 60-kilowatt multiphase brushless permanent magnet (PM) motors **14** and **16** that are mounted to a multi-speed electrically variable transmission (EVT) **18**. The illustrated automobile **10**—also referred to herein as "motor vehicle" or "vehicle" for short—is merely an exemplary application with which novel aspects and features of this disclosure can be practiced. Additionally, implementation of the present concepts into a dual-mode, power-split hybrid electric powertrain should also be appreciated as an exemplary application of the novel concepts disclosed herein. As such, it will be understood that aspects and features of the disclosure can be applied to other powertrain configurations, utilized for any logically relevant type of motor vehicle, and implemented in automotive and non-automotive applications alike. Lastly, only select components have been shown and will be described in additional detail herein. Nevertheless, the vehicles, systems and devices discussed below can include numerous additional and alternative features, and other commercially available peripheral components, e.g., for carrying out the various methods and functions of this disclosure.

The hybrid powertrain **11** of FIG. **1** may be designed to launch and propel the vehicle **10**, to operate the vehicle in all speed ranges between low and high road speeds, and to power any or all of the onboard vehicle electronics. An "electrically variable transmission," as shown in the drawings, comprises a transmission planetary gear train operatively connected to each of the engine **12**, the first motor/generator unit (MGU) **14**, and the second MGU **16**. Channeling respective torques of the engine **12** and the two motor/generator units **14**, **16** (referred to interchangeably as "traction motors") to different members of the planetary gear train permits one of the power sources to either assist or balance the operation of any of the other two power sources. Thus, the combination of an engine **12** and multiple motor/generator units **14**, **16** operatively connected to the EVT **18** allows speeds and torques of the engine and motor/generators to be controlled and selected independently in order to power a subject vehicle **10** more efficiently.

The vehicle **10** is equipped with a vehicle battery system **15** that may comprise, for example, multiple battery cells packaged as battery modules that are stacked into multiple traction battery packs 21A and 21B. These battery cells may utilize any suitable battery technology, including, for example, lead-acid, nickel-metal hydride (NiMH), lithium-ion ("Li-Ion"), Li-Ion polymer, zinc-air, lithium-air, nickel-cadmium (NiCad), valve-regulated lead-acid ("VRLA"), including absorbed glass mat ("AGM"), nickel-zinc (NiZn), molten salt (e.g., a Na—$NiCl_2$ battery), or any combination thereof. Each battery pack or each battery cell may be associated with one or more sensors to measure one or more battery characteristics (e.g., voltage, current, temperature, SOC, capacity, etc.) associated with each pack/cell. The vehicle battery system **15** is operatively connected to the motor/generators units **14**, **16** to transfer electrical current to and receive electrical current from these MGUs.

Resident vehicle controller **23** is communicatively connected to the engine **12**, traction motors **14**, **16**, vehicle battery system **15**, and transmission **18** to control the operation thereof. Controller, control module, module, control unit, processor, and central processing unit, including any permutations thereof, may be used interchangeably to reference suitable computing hardware and attendant logic. These terms may be defined to mean any one or various combinations of one or more of logic circuits, Application Specific Integrated Circuit(s) (ASIC), electronic circuit(s), central processing unit(s) (e.g., microprocessor(s)), and associated memory and storage (e.g., read only, programmable read only, random access, hard drive, tangible, etc.)), combinational logic circuit(s), input/output circuit(s) and devices, etc., whether resident, remote, or a combination of both.

Vehicle controller **23** may be integrated circuit (IC) hardware programmed to execute one or more software or firmware programs or routines, e.g., using appropriate signal conditioning and buffer circuitry, and other components to provide the described functionality. Software, firmware, programs, instructions, routines, code, algorithms and similar terms may be defined to mean any controller-executable instruction sets, including calibrations and look-up tables. A controller may be designed with a set of control routines executed to provide one or more desired functions. Control routines are executed, such as by a central processing unit, and are operable to monitor inputs from sensing devices and other networked control modules, and execute control and diagnostic routines to control operation of devices and actuators. Routines may be executed in real-time, continuously, systematically, sporadically and/or at regular intervals, for example, each 100 microseconds, 3.125, 6.25, 12.5, 25 and 100 milliseconds, etc., during ongoing vehicle use. Alternatively, routines may be executed in response to occurrence of an event during operation of the vehicle **10**.

Selectively operable as a continuously variable power transmission, EVT **18** of FIG. **1** includes multiple gear trains, such as a first planetary gear set (PGS) **22**, a second PGS **24**, and a gear train **44**, and helps to define a compound-power-split hybrid powertrain **11** architecture by incorporating a compound planetary gear arrangement **20**. This compound planetary gear arrangement **20** is composed of two members of the first PGS **22** being operatively connected to two members of the second PGS **24**. First PGS **22** is composed of a ring gear member **28**, a planet carrier member **30**, and a sun gear member **32**. One or more planet gears **29** is/are intermeshed with the ring gear **28** and mounted on the planet carrier member **30**, while the sun gear member **32** is intermeshed with the planet gear(s) **29** and concentrically aligned within the ring gear **28**. In this regard, the second PGS **24** includes a ring gear member **34**, a planet carrier member **36**, and a sun gear member **38**. One or more planet gears **35** is/are intermeshed with the ring gear **34** and mounted on the planet carrier member **36**, while the sun gear member **38** is intermeshed with the planet gear(s) **35** and concentrically aligned within the ring gear **34**.

The carrier member **36** of the second gear set **24** is interconnected with the sun gear member **32** of the first gear set **22**, e.g., to rotate in unison therewith. The ring gear member **34** of the second gear set **24** is interconnected with the carrier member **30** of the first gear set **22** e.g., to rotate in unison therewith. Finally, the ring gear member **28** of the first gear set **22** is shown interconnected with a transfer gear train **44**. The junction points of the EVT **18** are represented by selectable and fixed interconnections such that the resultant structure effectively generates a multi junction point lever when selectable torque transmitting-devices C-**0**, C-**1**, C-**2**, C-**3** and C-**4** are engaged and disengaged individually and in select combinations.

As portrayed in FIG. **1**, the engine **12** and the first motor/generator unit **14**, or at least the respective torque-transmitting output shafts thereof, may be disposed for rotation on a common first rotating axis A**1**. Conversely, the second motor/generator unit **16**, or at least the torque-transmitting output shaft thereof, may be disposed for rotation on a second rotating axis A**2**. According to the illustrated example, the first axis A**1** is substantially parallel to the second axis A**2**. The gear-train **44** of FIG. **1** is configured to operatively connect the second motor/generator unit **16** to the compound planetary gear arrangement **20** at a corresponding junction point. The gear-train **44** may be configured as either a single-stage or a two-stage parallel shaft gear set or as a third PGS.

Engine **12**, first MGU **14**, and second MGU **16** are operatively connected to the EVT **18** via input member arrangements that transmit torque between the tractive power sources and the compound planetary gear arrangement **20**. By way of non-limiting example, the input member arrangement includes: an engine output shaft of the engine **12**, which serves as an engine input/output member **46**; a rotor of the first MGU **14**, which serves as a first motor input/output member **48**; and a rotor of the second MGU **16**, which serves as a second motor input/output member **50**. The engine input/output member **46** provides engine torque to the EVT **18**, whereas motor input/output members **48**, **50** provide torque from their respective motor/generator units **14**, **16** to the EVT **18**. A damper assembly **64**, which is operatively connected to the input/output shaft **46** of the engine **12**, is configured to absorb torsional vibrations generated by the engine **12** before such vibrations can be transmitted to the planetary gear arrangement **20** of EVT **18**.

It may be desirable for the first motor input member **48** to be continuously connected or selectively connectable (e.g., via torque transmitting device C-**0**) to the sun gear member **38**. Second motor input member **50** may be continuously connected or selectively connectable (e.g., via torque transmitting device C-**4**) to the gear train **44**. The EVT **18** also includes an output member **52**, which may be in the nature of a transmission output shaft, that is continuously connected or selectively connectable to a third junction point. In order to launch and propel the vehicle **10**, output member **52** is operable to transmit torque from the compound planetary gear arrangement **20** to a final drive system **13**, which is represented herein by differential **17**, drive wheels **19** and axle **25**. Regenerative braking may be achieved by transferring torque from the final drive system **13**, through the output member **52** and EVT **18**, to the MGUs **14**, **16** when operating in an electric generator mode.

The ICE assembly **12** operates to propel the vehicle **10** independently of the traction motors **14** and **16**, e.g., in an "engine-only" operating mode, or in cooperation with either or both motors **14** and **16**, e.g., in a "motor-boost" and/or a "motor-launch" operating mode. In the example depicted in FIG. **1**, the ICE assembly **12** may be any available or hereafter developed engine, such as a two or four-stroke compression-ignited diesel engine or a four-stroke spark-ignited gasoline or flex-fuel engine, which is readily adapted to provide its available power output typically at a number of revolutions per minute (RPM). Although not explicitly portrayed in FIG. **1**, it should be appreciated that the final drive system **13** may take on any available configuration, including front wheel drive (FWD) layouts, rear wheel drive (RWD) layouts, four-wheel drive (4WD) layouts, all-wheel drive (AWD) layouts, etc.

Turning next to FIG. **2**, there is shown an onboard rechargeable energy storage system (RESS) **115** that is adapted for storing high-voltage electrical energy used for propelling an electric-drive vehicle, such as hybrid electric vehicle **10** of FIG. **1**. RESS **115** may be a deep-cycle, high-ampere capacity battery system rated for approximately 400 to 800 VDC or more, for example, depending on a desired vehicle range, gross vehicle weight, and power ratings of the various loads drawing electrical power from the RESS **115**. To this end, the RESS **115** may include multiple high-voltage, independently-rechargeable battery packs **121**A and **121**B that are selectively electrically connectable to one or more polyphase electric machines, such as three-phase traction motor **114**. While only two traction battery packs **121**A, **121**B and one traction motor **114** are shown in FIG. **2** for illustrative simplicity, a single traction battery pack or three or more traction battery packs may be used within RESS **115** to power any number of electric traction motors.

The first (B**1**) and second (B**2**) traction battery packs **121**A, **121**B may be connected in electrical parallel with respect to a high-voltage main DC bus **160** and a power inverter module **162** for governing the transmission of electrical energy to and from the traction motor **114**. Each pack **121**A, **121**B comes equipped with a respective stack **161**A and **161**B of battery cells, including lithium ion cells, lithium polymer cells, or any other rechargeable electrochemical cells providing a sufficiently high-power density, as well as any requisite conductive battery support structure and current conditioning hardware. The number and arrangement of battery cells **161**A, **161**B in each pack **121**A, **121**B may vary with the intended application of the RESS **115**, for instance with 96 or more such cells per pack used in certain high-voltage applications. Although differing in appearance, the RESS **115** of FIG. **2** may include any of the options and features described above with respect to the vehicle battery system **15** of FIG. **1**, and vice versa.

A DC-to-AC and AC-to-DC power inverter module **162**, which may be part of a transmission power inverter module (TPIM), connects via polyphase windings **166** to traction motor **114** to transmit electrical energy between the motor **114** and battery packs **121**A, **121**B. The power inverter module **162** may incorporate multiple power inverters and respective motor control modules operable to receive motor control commands and control inverter states therefrom for providing motor drive or regenerative functionality. The power inverter module **162** may comprise a set **164** of semiconductor switches S_{11}-S_{16} (also referred to herein as "inverter switches") that cooperatively convert direct current power from the energy storage devices—battery packs **121**A, **121**B—to alternating current power for powering the electric machine **114** via high-frequency switching. Each semiconductor switch S_{11}-S_{16} may be embodied as a voltage-controlled bipolar switching device in the form of insulated gate bipolar transistor (IGBT), metal-oxide semiconductor field effect transistor (MOSFET), wideband GaN device (WBG), or other suitable switch having a corresponding gate to which a gate signal is applied to change the on/off state of a given switch. There is typically at least one semiconductor switch for each phase of a three-phase electric machine.

The traction battery packs **121**A, **121**B include a set **168** of solid-state relay switches or contactors S**1**-S**3** (also referred to herein as "pack contactor switches") that are independently responsive to signals from a suitable controller or dedicated control module to govern the electrical output of the battery system **115**. Contactors/switches S**1**-S**3** are adapted to close under electrical load so as to ensure the instantaneous or near instantaneous delivery of electrical power to the vehicle's propulsion system and to drive any number of in-vehicle accessories. As with the semiconductor inverter switches **164** within the power inverter module **162**, pack contactor switches **168** may be constructed of highly efficient switching device, such as wide-gap gallium nitride (GaN) or silicon carbide (SiC) MOSFETs, IGBTs, or other suitable electronic devices. The first pack contactor switch S**1** is in electrical series with the first traction battery pack **121**A and in electrical parallel with the second traction battery pack **121**B. In this regard, second pack contactor switch S**2** is in electrical series with the second traction battery pack **121**B and in electrical parallel with the first traction battery pack **121**A. Contrarywise, third pack contactor switch S**3** is in electrical series with both traction battery packs **121**A, **121**B.

A DC output voltage of the traction battery packs **121**A, **121**B is delivered across positive and negative voltage bus rails **170**A and **170**B, respectively, with a fixed-type, high-frequency DC bulk capacitor **172** placed in electrical parallel with both traction battery packs **121**A, **121**B. The high-frequency DC bulk capacitor **172** is portrayed in FIG. **2** as a single device for ease of illustration. It should be appreciated, however, that the DC bulk capacitor **172** may be composed of multiple capacitor devices that are electrically arranged in series, parallel, or any other suitable electrical configuration to provide electrical capacitance in the electric circuit between the positive and negative conductors of the high-voltage main DC bus **160**. An RESS sensing system (not shown) may be arranged to monitor operating parameters of the main DC bus **160** and bulk capacitor **172**, such as a bus electrical potential measured across the positive and negative bus rails **170**A and **170**B of the high-voltage main DC bus **160**.

High-frequency DC bulk capacitor **172** is constructed with an interleaved busbar package that helps to reduce parasitic inductance while ensuring the symmetrical distribution of electrical current across the internal capacitor devices, which in turn increases the operational life expectancy of the component. By reducing stray inductance, the bulk capacitor **172** architecture also enables operation of the inverter power stage at high frequencies. As will be described in additional detail below, power loop inductance is reduced by widening and overlapping the bulk capacitor's positive and negative busbars. The DC bulk capacitor **172** is also provided with internal structure that physically supports, retains, and provides high-voltage isolation for the internal capacitor devices. The overall bulk capacitor package is modular and, thus, can be easily scaled to functionally connect 2, 4, 6, 8, 10, or more capacitor bobbins. The bulk capacitor **172** helps to ameliorate: (1) ripple current due to inverter switching; (2) voltage fluctuation due to the source lead inductance; (3) voltage transients due to leakage inductance and fast device switching; and (4) over voltage due to regeneration. What's more, resonances are eliminated from the input impedance of the bulk capacitor using disclosed interleaved busbar designs.

Capacitor size of the DC bulk capacitor **172** may be described in terms of its total capacitance, and may be selected based upon any number of variables, including expected voltage range, peak current, and ripple voltage amplitude across the main DC bus **160**. In this regard, capacitance of a bulk capacitor may also be determined in relation to parameters such as peak voltage, root mean square (RMS) current, minimum and maximum bus current levels, operating temperatures, and other factors. As such, the size of the DC bulk capacitor **172**, in terms of its total capacitance, may be selected based upon expected DC bus voltage ripple when operating the power inverter module **162** employing, for example, a six-step mode of operation. As yet another option, the DC bulk capacitor **172** may take on the form of any suitable electrical capacitive storage device, be it electrolytic devices, aluminum devices, ceramic devices, plastic capacitance devices, wound film devices, etc. Furthermore, the conductive material employed by each capacitor device may comprise any suitable electrically conductive material, such as aluminum, copper, gold, zinc, or an alloy or composite of the foregoing metallic materials.

FIG. **3** presents a representative high-frequency DC bulk capacitor **272** that is electrically connected to a representative power inverter module **262** for maintaining high-current, high-frequency power transmission with smoothed bus voltage. As indicated above, the power inverter module **262** and bulk capacitor **272** may be incorporated into the representative applications of FIGS. **1** and **2** and, thus, can include any of the corresponding options and features associated with the vehicle **10** and RESS **115** (and vice versa). Power inverter module **262** is generally composed of an electrically conductive base plate **212**, an electrically insulative PIM housing **214**, three conductive PIM tabs **216**, six semiconductor switches **218**, and a control resistor board (not visible in the view provided). Base plate **212** may be fabricated as a solid slab of conductive material, such as copper or aluminum, without any electrically or thermally insulative material. Antithetically, the PIM housing **214** is fabricated from an insulative material, such as a plastic, epoxy, and/or epoxy-impregnated fiber glass. The PIM housing **214** may be rigidly coupled to the base plate **212** using, for example, threaded fasteners **220**. The semiconductor switches **218** may be mounted to the PIM housing **214**, e.g., as unpacked or "bare" dice in a 3×2 matrix. An active (drain) terminal of each switch **218** is electrically connected to the base plate **212** while an active (source) terminal is electrically connected to the conductive PIM tabs **216**.

With collective reference to FIGS. **3** and **4**, bulk capacitor **272** contains, among other things, a bank of four (4) conduction-cooled or immersion-cooled, wound film capacitors **222** that are mounted within a hermetically sealable, box-shaped outer housing **224**. These wound film capacitors **222** (or "capacitor devices") help to protect the semiconductor switches **218** from repetitive transient voltages arising during the normal course of operation of the power inverter module **262**. In accord with the illustrated example, the capacitor devices **222** provide bulk filtering to attenuate attendant voltage fluctuations associated with a ripple current across a high-voltage bus, such as main DC bus **160** of FIG. **2**. Each capacitor device **222** within the bank of capacitors defines a single capacitive cell with negative and positive terminals **221** and **223**, respectively. Those skilled in the art will recognize that, although the terminals **221**, **223** are referred to herein as positive and negative, bulk film capacitors are typically not polarized. Capacitor devices **222** each constitutes a capacitive element, which may comprise alternating layers of metallized foil and insulative dielectric film that are spirally wound about a thermally conductive, tubular bobbin. An insulation lining jacket **226** is shown wrapped around an outer perimeter of the stacked array of capacitor devices **222**. In addition, an isolation endcap **228** is mounted on and electrically insulates a respective longitudinal end of each capacitor device **222**. Lining jacket **226** and endcaps **228** may be formed from any suitable electrically insulating material, including polypropylene, polytetrafluoroethylene, polyimide, and polyester, as well as the other insulative materials described above.

Interposed between the capacitor devices **222** and the bulk capacitor's outer housing **224** is an interleaved busbar package, designated generally as **230** in the Figures. For at least some implementations, it may be desirable that the interleaved busbar package **230** is a tripartite unit that consists essentially of a first (negative) busbar plate **232**, a second (positive) busbar plate **234**, and an isolator (barrier) sheet **236** interleaved between the two busbar plates **232**, **234**. The components of the interleaved busbar package **230** may each be fabricated as a discrete, single-piece structure; the three pieces are subsequently assembled into the final busbar package **230**, as best seen with respect to the workflow diagram of FIG. **4** and the exploded view of FIG. **5**. The first busbar plate **232** may be cut and stamped from metallic sheet stock and thereafter electrically connected to first (negative) terminals **221** of the four capacitor devices **222**. In the same vein, the second busbar plate **234** may be cut and stamped from metallic sheet stock and then electrically connected to second (positive) terminals **223** of the four capacitor devices **222**. It should be appreciated that use of the first busbar plate **232** as a negative busbar connector and the second busbar plate **234** as a positive busbar connector is application-specific and, thus, may be interchanged for other implementations. The isolator sheet **236** may be cut from insulative paper sheet stock to electrically isolate the first busbar plate **232** from second busbar plate **234**. The shapes, sizes, materials, and manufacturing methods may be varied from that which are shown in the drawings and discussed above.

Referring next to FIG. **5**, the three constituent parts of the interleaved busbar package **230** may have complementary geometries that allow the components to stack one inside the other in a layered fashion. For instance, the first busbar plate **232** has a distinct (first) U-shaped cross-section that is generally typified by a pair of (first) planar sidewalls **231**A and **231**B that adjoin and project generally orthogonally from opposite sides of an intermediate (first) planar base **229**. Along these lines, the second busbar plate **234** has a distinct (second) U-shaped cross-section that may be generally typified by a pair of (second) planar sidewalls **235**A and **235**B that adjoin and project generally orthogonally from opposite sides of an intermediate (first) planar base **233**. A "U-shaped cross-section", as used herein, may be characterized as a two-dimensional orthographic projection taken by cutting each part down the center along a transverse vertical plane that extends from left-to-right along section line A-A in FIG. **5**. The representative busbar plate cross-sections are distinct in that the sidewall-to-sidewall width W_2 of the second busbar plate's U-shaped cross-section is narrower than the sidewall-to-sidewall width W_1 of the first busbar plate's U-shaped cross-section. In so doing, the second busbar plate **234** nests within a 3-sided busbar pocket **238** defined by the sidewalls **231**A, **231**B and base **229** of the first busbar plate **232**. Once fit compactly together, the horizontal base **229** of the first busbar plate **232** is substantially parallel with the horizontal base **233** of the second busbar plate **234**, and the vertical sidewalls **231**A, **231**B, **235**A, **235**B are mutually parallel.

Isolator sheet **236** is also fashioned with a complementary shape that allows it to fit inside the busbar plate's pocket **238**, sandwiched between the two busbar plates **232**, **234**. By way of non-limiting example, isolator sheet **236** has a distinct (third) U-shaped cross-section that is generally typified by a pair of (third) planar sidewalls **239**A and **239**B that adjoin and project generally orthogonally from opposite sides of an intermediate (third) planar base **237**. The sidewall-to-sidewall width W_3 of the isolator sheet **236** is slightly narrower than the width W_1 of the U-shaped cross-section of the first busbar plate **232** yet slightly wider than the width W_2 of the U-shaped cross-section of the second busbar plate **234**. This allows the isolator sheet **236** to insert between the two busbar plates **232**, **234**, with opposing sides of the isolator sheet base **237** laying substantially flush against the busbar plate bases **229**, **233**, and opposing sides of each isolator sheet sidewall **239**A, **239**B laying substantially flush against respective busbar plate sidewalls **231**A, **235**A and **231**B, **235**B, respectively. After fully assembling the interleaved busbar package **230**, the "capped and wrapped" array of capacitor devices **222** rigidly mount inside a 3-sided capacitor basin **240** defined by the second busbar plate **234**. The busbar package **230** therefore acts as a divider that spaces the capacitor devices **222** from inner surfaces of the bulk capacitor's outer housing **224**. Any remaining gaps between the housing **224** and capacitor devices **222** may be filled with an epoxy endfill composition **242**.

Interleaved busbar package **230** provides local high-current power distribution to and from the capacitor devices **222**. The first busbar plate **232** is fabricated with multiple (first) windows: busbar plate **232** is shown with a total of eight (8) windows **241** in FIG. **5**, four (4) of which are arranged in a 2×2 matrix punched or laser cut through each sidewall **231**A, **231**B. Along those lines, the second busbar plate **234** is also fabricated with multiple (second) windows: busbar plate **234** is shown with a total of eight (8) windows **245** in FIG. **5**, with four (4) windows **245** arranged in a 2×2 matrix punched or laser cut through each sidewall **235**A, **235**B. Likewise, the isolator sheet **236** is fabricated with multiple (third) windows: isolator sheet **236** is shown with eight (8) windows **249** in FIG. **5**, with four (4) windows **249** arranged in a 2×2 matrix extending through each sidewall **239**A, **239**B. While any functionally suitable shape may be implemented, the representative windows **241**, **245**, **249** all have rectangular shapes, with the first windows **241** being larger than the second and third windows **245**, **249**, and the third windows **249** being the smallest of the windows **241**, **245**, **249**. When the interleaved busbar package **230** is assembled, each of the first windows **241** aligns with a second and a third window **245**, **249** such that all three aligned windows **241**, **245**, **249** line up with a longitudinal end of a capacitor device **222**. Each endcap **228** is also provided with a window **227** (FIG. **4**) that forms an unobstructed path to a longitudinal end of a capacitor device **222**.

For each sidewall **231**A, **231**B and **235**A, **235**B of the first and second busbar plates **232**, **234**, a subset of the corresponding windows **241**, **245** is provided with electrical connectors for electrically coupling that busbar plate **232**, **234** to the capacitor devices **222**. According to the illustrated example presented in FIGS. **4** and **5**, two of the four windows **241** in each sidewall **231**A, **231**B—one diagonally offset from the other—each has three (3) elongated (first) electrical fingers **251** projecting into that window **241**. Likewise, two of the four windows **245** in each sidewall **235**A, **235**B—one diagonally offset from the other—each has three (3) elongated (second) electrical finger **255** projecting into that window **245**. Each finger **251**, **255** is electrically connected, e.g., via soldering, fusing, welding, or other suitable means to one of the terminals **221**, **223** of the capacitor devices **222**. Electrical fingers **251** of the first busbar plate **232** may be arranged in opposite windows to that of the electrical fingers **255** of the second busbar plate **234**. The bottom center view of the DC bulk capacitor **272** in FIG. **4** shows that, once the capacitor **272** is fully assembled, the first busbar plate's fingers **251** are located in the upper-right and bottom-left windows **241**, whereas the second busbar plate's fingers **255** are located in the upper-left and bottom-right windows **245**. Although shown with three rectangular fingers **251**, **255**, the subset of windows **241**, **245** may be provided with greater or fewer than three electrical connectors of varying shapes and orientations.

A rectangular (first) connector pad **253** is integrally formed with and projects generally orthogonally from one sidewall **231**B of the first busbar plate **232**. This connector pad **253** electrically connects, e.g., via laser welding, to the power inverter module **262** and, through there, an electrical load, such as MGUs **14** and **16** of FIG. **1** or traction motor **114** of FIG. **2**. A square-shaped (first) connector tab **263** is integrally formed with and projects generally orthogonally from the other sidewall **231**A of busbar plate **232**. Connector tab **263** electrically connects the DC bulk capacitor **272**, e.g., via conductive bolts, to a power source, such as traction battery packs **21**A, **21**B of FIG. **1** or traction battery packs **121**A, **121**B of FIG. **2**. Furthermore, a rectangular (second) connector pad **257** is integrally formed with and projects generally orthogonally from one sidewall **235**B of the second busbar plate **234**. Like connector pad **253**, connector pad **257** electrically connects, e.g., via laser welding, to the power inverter module **262** and, thus, a traction motor. A square-shaped (second) connector tab **267** is integrally formed with and projects generally orthogonally from the other sidewall **235**BA of busbar plate **234**. Like the first busbar's connector tab **263**, connector tab **267** electrically connects the DC bulk capacitor **272** to a power source.

With continuing reference to FIGS. **3-5**, the isolator sheet **236** electrically insulates the electrical connection points of the first and second busbar plates **232**, **234**. For instance, the isolator sheet **236** is fabricated with a rectangular pad isolator **259** that is integrally formed with and projects generally orthogonally from sidewall **239**B. As the name implies, pad isolator **259** lays between and physically separates the first and second connector pads **253**, **257**. Furthermore, a generally Z-shaped tab isolator **261** is integrally formed with and projects generally orthogonally from sidewall **239**A. Tab isolator **261** is interposed between and physically separates the two connector tabs **263**, **267**.

Aspects of the present disclosure have been described in detail with reference to the illustrated embodiments; those skilled in the art will recognize, however, that many modifications may be made thereto without departing from the scope of the present disclosure. The present disclosure is not limited to the precise construction and compositions disclosed herein; any and all modifications, changes, and variations apparent from the foregoing descriptions are within the scope of the disclosure as defined by the appended claims. Moreover, the present concepts expressly include any and all combinations and subcombinations of the preceding elements and features.

What is claimed:

1. A bulk capacitor, comprising:
an outer housing;
a plurality of capacitor devices disposed within the outer housing and operable to modify an electric current transmitted between a power source and an electrical load, the capacitor devices being grouped into a stack of the capacitor devices;
a lining jacket wrapped around and electrically insulating an outer perimeter of the stack of the capacitor devices;
a plurality of isolation endcaps mounted on and electrically insulating longitudinal ends of the capacitor devices; and
an interleaved busbar package interposed between the capacitor devices and the outer housing, the interleaved busbar package including:
a first busbar plate electrically connected to first terminals of the capacitor devices and defining a busbar pocket;
a second busbar plate seated within the busbar pocket and electrically connected to second terminals of the capacitor devices, the second busbar plate defining a capacitor basin seating therein the capacitor devices; and
an isolator sheet interleaved between the first and second busbar plates and electrically insulating the first busbar plate from the second busbar plate.

2. The bulk capacitor of claim 1, wherein the first busbar plate has a first U-shaped cross-section, and the second busbar plate has a second U-shaped cross-section narrower than the first U-shaped cross-section.

3. The bulk capacitor of claim 2, wherein the first U-shaped cross-section has a pair of first sidewalls connected via a first base, and the second U-shaped cross-section has a pair of second sidewalls connected via a second base, the second base being substantially parallel with the first base, and the second sidewalls being substantially parallel with the first sidewalls.

4. The bulk capacitor of claim 3, wherein the isolator sheet has a third U-shaped cross-section narrower than the first U-shaped cross-section and wider than the second U-shaped cross-section.

5. The bulk capacitor of claim 4, wherein the third U-shaped cross-section has a pair of third sidewalls connected via a third base, the third base laying substantially flush against the first and second bases, and the third sidewalls each laying substantially flush against a respective one of the first sidewalls and a respective one of the second sidewalls.

6. The bulk capacitor of claim 1, wherein the first busbar plate has a pair of first sidewalls connected via a first base, and multiple first windows extending through each of the first sidewalls, the first windows being aligned with the longitudinal ends of the capacitor devices.

7. The bulk capacitor of claim 6, wherein the first busbar plate further includes multiple first electrical fingers projecting into each window of a subset of the first windows and electrically connecting to the first terminals of the capacitor devices.

8. The bulk capacitor of claim 7, wherein the first busbar plate further includes a first connector pad projecting from one of the first sidewalls and configured to electrically connect, directly or indirectly, to the electrical load, and a first connector tab projecting from another of the first sidewalls and configured to electrically connect, directly or indirectly, to the power source.

9. The bulk capacitor of claim 8, wherein the second busbar plate has a pair of second sidewalls connected via a second base, and multiple second windows extending through each of the second sidewalls, the second windows being aligned with the first windows and with the longitudinal ends of the capacitor devices.

10. The bulk capacitor of claim 9, wherein the second busbar plate further includes multiple second electrical fingers projecting into each window of a subset of the second windows and electrically connecting to the second terminals of the capacitor devices.

11. The bulk capacitor of claim 10, wherein the second busbar plate further includes a second connector pad projecting from one of the second sidewalls and configured to electrically connect, directly or indirectly, to the electrical load, and a second connector tab projecting from another of the second sidewalls and configured to electrically connect, directly or indirectly, to the power source.

12. The bulk capacitor of claim 11, wherein the isolator sheet further includes a pair of third sidewalls connected via a third base, a pad isolator projecting from one of the third sidewalls and interleaved between the first and second connector pads, and a tab isolator projecting from another of the third sidewalls and interposed between the first and second connector tabs.

13. The bulk capacitor of claim 12, wherein the isolator sheet further includes multiple third windows extending through each of the third sidewalls, the third windows being aligned with the first and second windows and with the longitudinal ends of the capacitor devices.

14. The bulk capacitor of claim 1, wherein the stack of the capacitor devices are arranged in an array of rows and columns, the bulk capacitor further comprising an epoxy endfill composition submerging the capacitor devices in the outer housing.

15. An electric-drive vehicle comprising:
a vehicle body with a plurality of road wheels;
a traction motor attached to the vehicle body and configured to drive one or more of the road wheels to thereby propel the electric-drive vehicle;
a traction battery pack attached to the vehicle body and configured to transmit an electric current with the traction motor; and
a bulk capacitor including:
an outer housing attached to the vehicle body;
a plurality of capacitor devices grouped into a stack of the capacitor devices, disposed within the outer housing, and operable to modify the electric current transmitted between the traction battery pack and the traction motor;
a lining jacket wrapped around and electrically insulating an outer perimeter of the stack of the capacitor devices;
a plurality of isolation endcaps mounted on and electrically insulating longitudinal ends of the capacitor devices; and
an interleaved busbar package placed between the capacitor devices and the outer housing, the interleaved busbar package including a first busbar plate electrically connected to first terminals of the capacitor devices and defining a busbar pocket, a second busbar plate seated within the busbar pocket and electrically connected to second terminals of the capacitor devices, the second busbar plate defining a capacitor basin seating therein the capacitor devices,

and an isolator sheet interleaved between the first and second busbar plates and electrically insulating the first busbar plate from the second busbar plate.

16. A method of assembling a bulk capacitor, the method comprising:

placing a plurality of capacitor devices within an outer housing, the capacitor devices being grouped into a stack of the capacitor devices and operable to modify an electric current transmitted between a power source and an electrical load;

wrapping an electrically insulating lining jacket around an outer perimeter of the stack of the capacitor devices;

mounting a plurality of electrically insulating isolation endcaps onto longitudinal ends of the capacitor devices; and

positioning an interleaved busbar package between the capacitor devices and the outer housing, the positioning of the interleaved busbar package including:

electrically connecting a first busbar plate to first terminals of the capacitor devices, the first busbar plate defining a busbar pocket;

electrically connecting a second busbar plate to second terminals of the capacitor devices, the second busbar plate being seated within the busbar pocket and defining a capacitor basin seating therein the capacitor devices; and

interleaving an isolator sheet between the first and second busbar plates to thereby electrically insulate the first busbar plate from the second busbar plate.

17. The method of claim **16**, wherein the first busbar plate has a first U-shaped cross-section, the second busbar plate has a second U-shaped cross-section narrower than the first U-shaped cross-section, and the isolator sheet has a third U-shaped cross-section narrower than the first U-shaped cross-section and wider than the second U-shaped cross-section.

18. The method of claim **17**, wherein the first U-shaped cross-section has a pair of first sidewalls connected via a first base, and the second U-shaped cross-section has a pair of second sidewalls connected via a second base, the second base being substantially parallel with the first base, and the second sidewalls being substantially parallel with the first sidewalls.

19. The method of claim **18**, wherein the third U-shaped cross-section has a pair of third sidewalls connected via a third base, the third base laying substantially flush against the first and second bases, and the third sidewalls each laying substantially flush against a respective one of the first sidewalls and a respective one of the second sidewalls.

20. The method of claim **19**, wherein:

the first busbar plate has multiple first windows extending through each of the first sidewalls;

the second busbar plate has multiple second windows extending through each of the second sidewalls; and

the isolator sheet has multiple third windows extending through each of the third sidewalls, the first, second, and third windows being aligned with each other and with the longitudinal ends of the capacitor devices.

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